RELATIONSHIP BETWEEN SENSORY AND INSTRUMENTAL TEXTURE PROFILE ATTRIBUTES

JEAN-FRANCOIS MEULLENET[1]

Dept. of Food Science
University of Arkansas
Fayetteville, AR 72704

B.G. LYON

USDA-ARS
P.O. Box 5677
Russell Research Center
Athens, GA 30604

JOHN A. CARPENTER

Dept. of Food Science and Technology
University of Georgia
Athens, GA 30601

C.E. LYON

USDA-ARS
P.O. Box 5677
Russell Research Center
Athens, GA 30604

Received for Publication June 18, 1997

ABSTRACT

Texture relationships were studied using both sensory and instrumental texture profile analysis (TPA) techniques to evaluate twenty-one food samples from a wide variety of foods. High linear correlations were found between sensory and instrumental TPA parameters for hardness (r = 0.76) and springiness (r = 0.83). No significant correlations were found between sensory and instrumental TPA parameters for cohesiveness and chewiness. Logarithmic transformations of data

[1]Corresponding author

Journal of Sensory Studies **13** (1998). 77-93.

improved correlations between sensory attributes and their instrumental corollaries. The correlation between sensory hardness and the logarithm of instrumental hardness was improved to r=0.96. The correlation between the logarithm of both sensory and instrumental springiness was improved to r=0.86. The correlation between the logarithms of both sensory and instrumental chewiness was improved to r=0.54, which was significant at P<0.05.

INTRODUCTION

Texture evaluation is often an important step in developing a new food product or optimizing processing variables. Both sensory evaluation techniques and instrumental measurements are used in food texture research to assess texture parameters. Correlations are generally used to assess the relationship between the instrumental measurement and sensory perception in order to predict consumer responses or to evaluate quality control tools or parameters (Szczesniak 1987). Frequently, the values of the correlations between the two evaluation methods are less than r= 0.80. Szczesniak (1968) stated that there are many pitfalls in applying linear correlation coefficients to experimental data. For instance, the meaning of the correlation coefficient, or the manner by which objective measurements are performed can influence the results. The psychological and methodological factors that influence the particular sensory evaluation tests may impact results. The heterogeneity of the test samples may also influence the nature and degree of correlation between sensory and instrumental measurements of food texture (Szczesniak 1968). Therefore, if the relationship between sensory and instrumental data is nonlinear, the calculation of a linear correlation coefficient between the two untransformed sets of data may not be appropriate. Szczesniak (1987) noted that failure to recognize this nonlinear relationship often results in poor statistical correlations. When correlations do not meet expectations, the fault is often directed toward sensory data rather than toward inappropriate selection of instrumental tests or statistical analyses.

A multitude of instrumental tests, both imitative and empirical, have been designed for the evaluation of texture characteristics of foods. Tests that attempt to imitate biting or chewing are popular since these tests generate multiple parameters. The most popular instrumental imitative tests, Texture Profile Analysis (TPA), was first developed for the General Foods Texturometer (Szczesniak *et al.* 1963) and later adapted to the Instron Universal Testing Machine (IUTM). The test was refined by Bourne (1978). Because of the amount of information generated, the Instron TPA double compression test has become very popular in the past two decades.

Texture descriptive panels are trained using the standard reference scales developed by Szczesniak *et al.* (1963) and expanded by Munoz (1986).

Researchers seek to select standard reference foods that exhibit a given attribute as a dominant characteristic. Nevertheless, food samples inherently possess and exhibit other nondominant textural characteristics. It is unknown how these nondominant texture attributes are perceived in the same foods used for profile training. Nor is it known how the inclusion of several nondominant characteristics in a sensory descriptive texture test might influence results of testing for the dominant characteristic.

Our objectives were to assess the relationships between the primary textural characteristics of hardness, cohesiveness, springiness, and chewiness when evaluated simultaneously in foods representing the food texture spectrum. Evaluations were performed by trained sensory texture panelists and by instrumental texture profile analysis.

MATERIALS AND METHODS

Samples

The samples used in this study were those described by Szczesniak *et al.* (1963) and Munoz (1986) when developing the texture reference scales (Table 1). Modifications of brands and types were necessary in some instances due to availability. A total of twenty-one samples were sized and tempered as recommended by Szczesniak (1963) and Munoz (1986) for evaluation by the instrument and by the trained panel. The twenty-one samples were evaluated by a trained sensory panel for hardness, cohesiveness, springiness and chewiness. The same samples were also instrumentally tested for the corresponding parameters using an Instron universal testing machine (Model 1122).

Sensory Descriptive Analysis

Seven panelists were screened and recruited from a pool of panelists trained for descriptive analysis of texture. Training procedures followed the guidelines defined by Civille and Szczesniak (1973), Munoz (1986), and Meilgaard *et al.* (1987). Panelists have received prior extensive training on the term definitions as well as exposure to suggested reference food samples. Numerical scales for scoring attribute intensities of references followed the 0-15 cm universal scale suggested by Spectrum methodology (Meilgaard *et al.* 1992). Where it was necessary to substitute items in place of a published reference standard for training, panel consensus was obtained to verify scale intensity placement.

Samples listed in Table 1 were evaluated and scored for the primary mechanical texture characteristics of hardness, cohesiveness, springiness and chewiness. The definitions for the sensory texture attributes were those from Szczesniak *et al.* (1963) and Munoz (1986). Hardness was the force required to

TABLE 1.
LIST OF SAMPLES USED IN MODELIZATION

#	Product	type/brand	Manufacturer	sample size	Temperature	Reference scale
1	Almond	Planter, shelled	Nabisco Brands	1 piece	room	hardness
2	American cheese	Yellow, pasteurized	Land O Lakes	1/2" cube	40 F	hardness cohesiveness
3	Caramel	Homemade , light	Robinson's Candies	1 piece	room	cohesiveness
4	Carrot	Uncooked, unpeeled	-	1/2" slice	room	hardness
5	Corn muffin	Old fashioned	Pepperidge Farm	1/2" cube	room	cohesiveness
6	Cream cheese	Philadelphia	Kraft	1/2" slice	40 F	hardness springiness
7	Egg white	Hard cooked (5minutes)	-	1/2" cube	room	hardness
8	Frankfurter 5 min	Beef franks, cooked 5 min.	Hebrew National Kosher Foods	1/2" slice	room	hardness
9	Frankfurter 10 min	Beef franks, cooked 10 min.	Hebrew National Kosher Foods	1/2" slice	room	springiness
10	Gelatin	Jell-O Knox gelatin	General Foods Co. Knox Gelatine inc.	1/2" cube	40 F	springiness
11	Gumdrop	Spicettes	Brach	1 piece	room	chewiness
12	Hard candy	Life Savers	Nabisco Brands	1 piece	room	hardness
13	Marshmallow	Miniature	Kraft	1 piece	room	springiness
14	Olive	Stuffed, Spanish type	Goya Foods	1 piece	room	hardness
15	Peanut	Planter, cocktail type	Nabisco Brands	1 piece	room	hardness
16	Prune	seedless	Sun Maid, Growers of california	1 piece	room	cohesiveness
17	Rye bread	Jewish Rye	Cobblestone Mill	1/2" square	room	chewiness
18	Soft pretzel	Dutchie, Pensylvania Dutch	United Products Co.	1/2" cube	room	cohesiveness
19	Fruit chew	Starburst	Mars Broke Division	1 piece	room	cohesiveness
20	Tootsie roll	Midgees	Tootsie Roll Industries, Inc.	1 piece	room	chewiness
21	White bread	Wonder, sliced, enriched	Continental Baking Co.	1/2" square	room	cohesiveness

bite completely through the sample when placed between molars. Cohesiveness was defined as the amount of deformation undergone by a material before rupture when biting completely through the samples using molars. Springiness was defined as the degree or rate at which the sample returns to its original size/shape after partial compression between the tongue and palate. The definition of chewiness was the total amount of work necessary to chew a sample to a state ready for swallowing.

All twenty-one samples were evaluated on each day of three test days. Samples were assigned an ID number from 1 to 21 for the test block assignment. On each test day, samples were randomly assigned by computer to one of four blocks. For each test block, all panelists received the same sample set but the sample presentation order was randomized across panelists. Samples were evaluated at individual test stations equipped for automated data input and transcription (Findlay 1986). There was a rest period between each test block to avoid fatigue.

Instrumental Texture Analysis

Each of the twenty-one food samples was evaluated instrumentally at the temperature recommended by Szczesniak *et al.* (1963) and Munoz (1986a) when developing the standard texture rating scales. The instrumental texture profile analysis (TPA) test described by Bourne (1978) was used. A two cycle compression was set for a 70% stain. A compression load cell (500 kg, INSTRON) interfaced with the series IX data acquisition software (INSTRON) was used to evaluate the stress applied to the samples during compression. The crosshead speed or loading rate was set to 100 mm/min for the evaluation of all samples. Parameters corresponding to sensory attributes were obtained from the curves. The test was configured so that the four TPA parameters, hardness, cohesiveness, springiness and chewiness, were calculated at the time of the test by determining the load and displacement at predetermined points on the TPA curve. Hardness (h_1) was the maximum load, expressed in kg, applied to the samples during the first compression. Cohesiveness (A_2/A_1) was the ratio of the area under the curve for the second compression (A_2) to that under the curve for the first compression (A_1). Springiness, expressed as d_2/d_1, was the ratio of the duration of contact with the sample during the first compression (d_2) to that during the first compression (d_1). Chewiness was the mathematical product of hardness, cohesiveness, and springiness ($h_1 \times A_2/A_1 \times d_2/d_1$). There were two replications of the instrumental analysis conducted on two separate days. For each replication, eight individual portions of each of the twenty-one food types were evaluated.

STATISTICAL ANALYSIS

Means and standard deviations were calculated for both sensory (n=21) and instrumental (n=16) data using PROC MEANS (SAS 1993). Means of response variables were transformed using logarithmic transformations. The transformations evaluated were selected based on the principles of psychophysics described by Meullenet *et al.* (1997). Pearson's correlation coefficients were calculated between all transformed and nontransformed response variables using PROC CORR (SAS 1993). A correspondence analysis was also conducted on the data (Senstools, v 2.0) to observe the consensus space of sample relationships.

RESULTS AND DISCUSSIONS

Sensory Panel and Texture Profile Analysis

Tables 2 and 3 list the means and standard deviations of sensory scores and instrumental measurements, respectively. The means for sensory and instrument scores showed that the twenty-one food samples used in this study spanned almost the entire range of values for texture scales based on standard reference foods. Because the standard deviations for the instrument scores were small, it was concluded that the instrumental test offered good reproducibility. Standard deviations for sensory scores were, in some cases, greater than expected, especially when evaluating cohesiveness. Because the food samples used in this study represented a broad range of textures, the evaluation of their texture profiles constituted a representative database and were useful in evaluating correlations between texture sensory attributes and their instrumental corollaries.

Correlation Analysis

Correlations Between Sensory Attributes. Pearson's correlation coefficient between sensory attributes are presented in Table 4. Hardness was negatively correlated with springiness ($r = -0.43$, $p<0.05$) and positively correlated with chewiness ($r = 0.77$, $p<0.001$). The negative correlation between hardness and springiness indicated that, in general, as the hardness of the products increased, their springiness decreased. Montejano *et al.* (1985) reported a positive correlation between firmness and springiness ($r = 0.85$, $p<0.0001$). In that study, samples of gels were used which covered only a particular area of the texture spectrum. The significance and importance of correlation coefficients may be relative to the type of product being studied. Cohesiveness was most highly correlated with chewiness ($r = 0.53$, $p<0.01$), and springiness was negatively correlated ($r = -0.44$, $p<0.05$) with chewiness. In general, the springier samples were less hard and less chewy.

TABLE 2.
SENSORY REFERENCE VALUES, STUDY MEAN SCORES AND STANDARD DEVIATIONS FOR PRIMARY MECHANICAL TEXTURE ATTRIBUTES OF FOOD REFERENCES

Food Samples	HARDNESS reference values	HARDNESS	COHESIVENESS reference values	COHESIVENESS	SPRINGINESS-reference values	SPRINGINESS	CHEWINESS reference values	CHEWINESS
creamcheese	**1.0**	**1.01 ± 1.22**		5.72 ± 1.86	**0.0**	**0.38 ± 0.65**		1.17 ± 1.3
egg white	**2.5**	**1.85 ± 1.52**		3.95 ± 2.12		4.70 ± 3.12		1.46 ± 1.32
cheese, American	**4.5**	**3.41 ±1.85**	**5.0**	**4.51 ± 2.51**		1.16 ± 1.11		3.18 ± 1.94
olive	**6.0**	**4.43 ± 1.33**		3.83 ± 1.86		2.19 ± 1.54		3.94 ± 1.44
frankfurter, 5min	**7.0**	**5.52 ± 1.48**		5.95 ± 1.39		6.27 ± 1.53		5.11 ± 1.18
peanut	**9.5**	**9.93 ± 1.66**		2.06 ± 1.99		0.10 ± 0.10		6.40 ± 2.12
carrot	**11.0**	**10.30 ± 2.72**		2.17 ± 2.52		0.30 ± 0.65		8.40 ± 3.28
almond	**11.0**	**10.90 ± 1.94**		2.21 ± 1.63		0.10 ± 0.31		7.42 ± 2.45
lifesaver	**14.5**	**14.10 ± 1.79**		1.00 ± 2.11		0.10 ± 0.52		8.36 ± 1.75
corn bread		0.83 ± 0.80	**1.0**	**0.68 ± 0.94**		0.39 ± 0.69		1.24 ± 0.97
white bread		0.95 ± 0.85	--	**6.91 ± 3.51**		2.20 ± 2.66		2.14 ± 1.68
pretzel		4.38 ± 1.83	**8.0**	**8.38 ± 3.25**		3.53 ± 2.68		6.63 ± 2.7
prune		2.78 ± 1.69	**10.0**	**9.32 ± 2.85**		2.11 ± 1.72		5.75 ± 2.16
Starburst		8.49 ± 2.99	**12.5**	**12.70 ± 1.75**		0.24 ± 0.23		11.20 ± 2.57
caramel		5.99 ± 1.89	**15.0**	**13.00 ± 1.87**		0.86 ± 2.53		11.90 ± 2.19
frankfurter, 10min		5.62 ± 1.52		6.13 ± 1.97	**5.0**	**5.50 ± 1.48**		5.36 ± 1.11
marshmallow		1.43 ± 1.25		7.89 ± 2.67	**9.5**	**8.85 ± 1.85**		2.02 ± 1.31
gelatin		2.35 ± 2.34		3.87 ± 2.23	**15.0**	**12.48 ± 2.36**		1.72 ± 1.63
rye bread		0.96 ± 0.70		6.57 ± 3.80		2.91 ± 3.00	***1.6 (10.3)**	**2.47 ± 1.96**
gumdrop		4.6 ± 2.33		7.7 ± 2.97		2.41 ± 1.37	***5.8 (25)**	**7.42 ± 2.55**
Tootsie Roll		10.7 ± 2.60		13.6 ± 1.28		0.83 ± 0.49	***12.8 (56.7)**	**12.83 ± 1.46**

Bold values indicate groups of primary characteristics with reference and observed values for attribute intensity of food products generally used to train panelists

* numbers in parenthesis are expressed in number of chews

TABLE 3.
INSTRUMENTAL VALUES FOR TPA CURVE PARAMETERS OBSERVED FOR REFERENCE FOOD PRODUCTS

SAMPLES	Hardness h1	Cohesiveness (A2/A1)	Springiness (d2/d1)	Chewiness (h1 x A2/A1 x d2/d1)
creamcheese	**0.94 ±0.09**	0.110 ±0.03	**0.19 ±0.06**	0.02 ±0.01
egg white	**1.31 ± 0.11**	0.442 ± 0.04	0.74 ± 0.02	0.42 ± 0.09
cheese, amer.	**5.13 ±0.41**	**0.201 ± 0.02**	0.38 ± 0.02	0.39 ±0.09
olive	**2.38 ±0.44**	0.101 ± 0.01	0.24 ±0.02	0.06 ±0.01
frankfurter, 5min	**5.24 ±0.25**	0.323 ± 0.02	0.74 ± 0.04	1.23 ± 0.22
peanut	**25.51 ± 7.64**	0.035 ± 0.01	0.15 ± 0.04	0.15 ± 0.09
carrot	**137.53 ± 10.81**	0.15 ± 0.04	0.45 ± 0.04	9.82 ± 3.33
almond	**40.59 ± 4.88**	0.075 ± 0.008	0.18 ± 0.03	0.68 ± 0.1
lifesaver	**201.9 ± 27.5**	0.055 ± 0.01	0.11 ±0.01	1.27 ±0.35
corn bread	0.47 ± 0.07	**0.101 ± 0.01**	0.26 ± 0.03	0.02 ± 0.01
white bread	0.28 ± 0.04	**0.385 ± 0.05**	0.71 ± 0.03	0.08 ± 0.02
pretzel	3.13 ± 0.23	**0.324 ± 0.04**	0.47 ± 0.05	0.38 ± 0.17
prune	3.69 ± 0.52	**0.186 ± 0.02**	0.29 ± 0.02	0.20 ± 0.02
starburst	20.43 ± 5.53	**0.051 ± 0.02**	0.11 ± 0.02	0.35 ± 0.17
caramel	8.76 ± 1.30	**0.130 ± 0.07**	0.21 ± 0.05	0.28 ± 0.27
frankfurter, 10min	5.38 ± 0.22	0.362 ± 0.05	**0.69 ± 0.04**	1.11 ± 0.16
marshmallow	2.11 ± 0.05	0.622 ± 0.02	**0.72 ± 0.02**	0.83 ± 0.03
gelatin	0.94 ± 0.07	0.749 ± 0.05	**0.87 ± 0.02**	0.61 ± 0.06
rye bread	0.31 ± 0.06	0.366 ±0.02	0.62 ± 0.05	**0.07 ± 0.01**
gumdrop	2.76 ± 0.17	0.273 ± 0.01	0.47 ± 0.02	**0.34 ± 0.04**
Tootsie Roll	49.25 ± 3.25	0.092 ± 0.02	0.21 ± 0.04	**0.96 ± 0.46**

Bold values indicate groups of foods used specifically to train panelists for one of the primary mechanical texture attributes. Order of listing follows the sensory intensity order.

Correlations Between Sensory Attribute and Instrumental Parameters (Untransformed Data). Correlation coefficients between sensory and instrumental data are also presented in Table 4. Sensory hardness was most highly correlated with instrumental hardness ($r = +0.77$, $p < 0.001$). This correlation coefficient was comparable to values reported in previous studies.

TABLE 4.
PEARSON'S CORRELATION COEFFICIENTS BETWEEN SENSORY ATTRIBUTES AND INSTRUMENTAL PARAMETERS

	sH	log(sH)	sC	log(sC)	sS	log(sS)	sCH	log(sCH)	iH	log(iH)	iC	log(iC)	iS	log(iS)	iCH	log(iCH)
sH	1.0	0.93	-[1]	-	-0.43	-0.66	0.77[2]	0.79	0.76	0.96	-0.56	-0.67	-0.54	-0.61	-	0.59
log(sH)		1.0	-	-	-	-0.47	0.82	0.88	0.58	0.93	-0.48	-0.55	-0.45	-0.49	-	0.66
sC			1.0	0.92	-	-	0.53	0.42	-	-	-	-	-	-	-	-
log(sC)				1.0	-	0.47	-	-	-0.47	-	-	-	-	-	-	-
sS					1.0	0.83	-0.44	-	-	-	0.93	0.81	0.83	0.75	-	-
log(sS)						1.0	-0.43	-	-0.57	-0.61	0.84	0.92	0.85	0.86	-	-
sCH							1.0	0.95	0.42	0.76	-0.53	-0.53	-0.54	-0.55	-	0.47
log(sCH)								1.0	-	0.79	-0.50	-0.48	-0.47	-0.46	-	0.54

sH = sensory hardness
sC = sensory cohesiveness
sS = sensory springiness
sCH = sensory chewiness

iH = instrumental hardness (h_1)
iC = instrumental cohesiveness (A_2/A_1)
iS = instrumental springiness (d_2/d_1)
iCH = instrumental chewiness ($h_1 x A_2/A_1 x d_2/d_1$)

[1] Correlation coefficients reported were only those statistically significant (i.e. $p<0.05$)
[2] The correlation table was arranged so that all four data transformations evaluation can be compared

Montejano *et al.* (1985) reported a significant correlation ($r = +0.74$, $p<0.001$) between instrumental hardness and sensory firmness. Pangborn *et al.* (1965) found a higher correlation ($r = 0.83$) between sensory force of bite and shear stress measured for turkey breasts. Munoz *et al.* (1986b) reported an even higher correlation ($r = 0.89$, $p<0.0001$) between sensory firmness and yield force of gelatin, sodium alginate and Kappa-carrageenan.

Montejano *et al.* (1985) also found a high correlation between instrumental cohesiveness and sensory hardness ($r = +0.74$, $p<0.001$). In the present study, with diverse food samples, a negative correlation ($r = -0.56$, $p<0.005$) was obtained between these two attributes. The instrumental measurement of cohesiveness (i.e. ratio A_2/A_1) was highly dependent on the springiness of the sample. For example, a sample, which exhibited very little springiness (such as caramel) would yield very low values for instrumental cohesiveness because there was very little contact with the samples during the second bite. Therefore the second peak area would be negligible. Montejano *et al.* (1985) used gel samples (one food system) that all exhibited some springiness.

The correlation between sensory cohesiveness and its instrumental corollary was statistically insignificant ($p>0.05$). Lyon *et al.* (1980) also reported very poor correlations between TPA cohesiveness and sensory notes for patties made with mechanically deboned poultry meat. Instrumental cohesiveness may not be an accurate predictor of the perceived sensory cohesiveness when comparing food samples belonging to different food systems. Description of sensory perception of cohesiveness may require more than the one physical measurement (A_2/A_1). The instrumental measurement of cohesiveness may provide a good evaluation of the sensory attribute cohesiveness for some food systems such as gels, but not for diverse food groups.

Sensory springiness was highly correlated with instrumental springiness ($r = 0.83$, $p<0.0001$). Furthermore, sensory springiness was also highly correlated with instrumental cohesiveness ($r = 0.93$, $p<0.0001$).

Montejano *et al.* (1985) reported that parameters from TPA tests represent more than a single sensory attribute. Significant correlations were found between sensory chewiness and instrumental hardness ($r = 0.42$, $p<0.05$), cohesiveness ($r = -0.53$, $p<0.05$) and springiness ($r = -0.54$, $p<0.05$). Instrumental chewiness was obtaining by multiplying the values for hardness, cohesiveness and springiness. The fact that sensory cohesiveness and chewiness were significantly correlated ($r = 0.53$, $p<0.05$), and that A_2/A_1 was not a good evaluation of cohesiveness, could explain the insignificant correlation between the sensory attribute and its instrumental corollary. The negative correlation between sensory chewiness and instrumental cohesiveness may be due to samples such as caramel, Tootsie Roll and Starburst candy. These were scored very chewy by the panelists, but instrumental cohesiveness was low according to the Instron evaluation. Therefore, the calculated instrumental chewiness was low for those samples (i.e. because cohesiveness was part of the calculated instrumental chewiness).

Statistically insignificant correlations between sensory chewiness and its instrumental corollary seem to be the norm rather than the exception. Two explanations are offered. First, because instrumental chewiness was calculated as the product of hardness, cohesiveness and springiness, the inadequacy of some of the measurements for instrumental cohesiveness may have influenced the calculated instrumental values of chewiness. A second explanation may be that the instrumental definition for chewiness does not correspond to the sensory perception of chewiness. Defining instrumental chewiness as the arithmetic result of multiplying the values of hardness, cohesiveness and springiness may be an over simplification. This point is illustrated in Fig. 1 and Fig. 2. Figure 1 is a plot of sensory chewiness versus the multiplicative result of sensory hardness × cohesiveness × springiness. It would be expected that if hardness, cohesiveness and springiness contributed equally to the overall sensory perception of chewiness, a trend would be observed in Fig. 1. The absence of a trend infers that the perception of chewiness involves additional attributes, and/or that these attributes do not contribute equally to the perception of chewiness. Figure 2 is a plot of instrumental chewiness versus the mathematical result of multiplying sensory hardness × cohesiveness × springiness. In Fig. 3, sensory chewiness versus instrumental chewiness was plotted. The presence of a trend in Fig. 2 and its subsequent absence in Fig. 3, demonstrates that instrumental chewiness (i.e. $h_1 \times A_2/A_1 \times d_2/d_1$) correlates better with the mathematical result of multiplying the values of sensory hardness × cohesiveness × springiness than with a single value of sensory chewiness, expressed as a value for perception of work.

Correlations Between Sensory Attributes and Instrumental Parameters (Transformed Data) (Table 4). Correlations between various combinations of transformed and untransformed data were also examined. For hardness, the use of data transformation (i.e. logarithmic) showed improved correlation of coefficients over those reported for untransformed data ($r=0.76$, $p<0.001$). The correlation between sensory hardness and the logarithm of its instrumental corollary was highly significant ($r=0.96$, $p<0.0001$). The correlation between both transformed variables was slightly lower ($r=0.93$, $p<0.0001$).

For cohesiveness, the use of data transformation did not improve the correlation coefficients to a significant level ($p>0.05$). For springiness, the correlation between the logarithm of both sensory springiness and instrumental springiness ($r=0.86$, $p<0.001$) showed a slight improvement over the correlation observed for untransformed data ($r=0.83$, $p<0.001$).

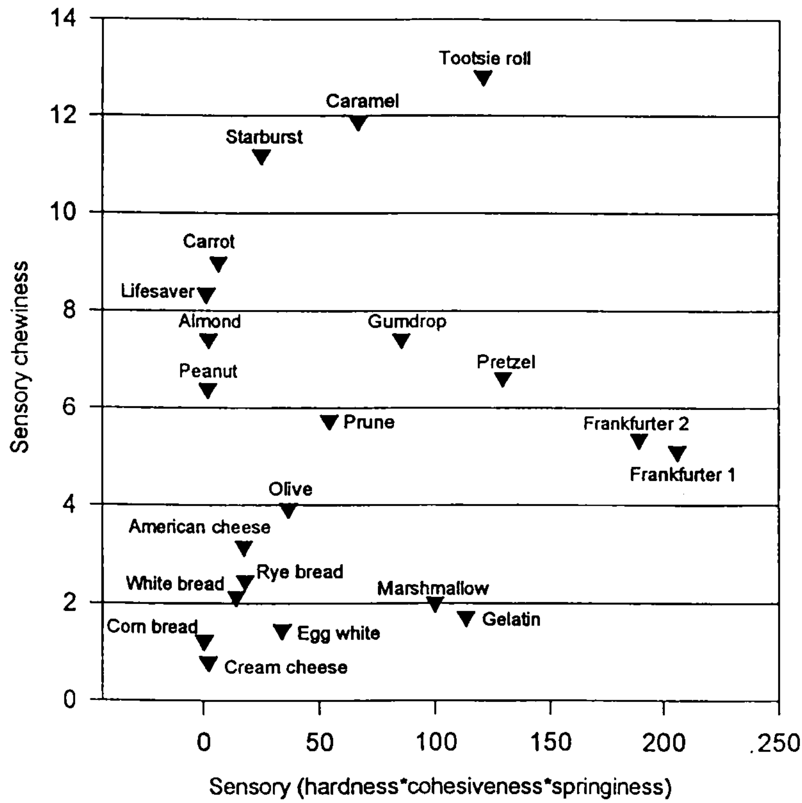

FIG. 1. SENSORY CHEWINESS VS (HARDNESS × COHESIVENESS × SPRINGINESS)

For chewiness, the use of data transformation brought the correlation coefficients to a significant level ($p<0.05$). The correlation between the logarithm of both sensory chewiness and its instrumental corollary was superior ($r=0.54$, $p<0.05$) to the correlation obtained between sensory chewiness and the logarithm of instrumental chewiness ($r=0.47$, $p<0.05$). Nevertheless, the correlation were too low to satisfactorily use instrumental chewiness as an accurate predictor of sensory chewiness.

Overall, correlation coefficients were improved through the use of logarithmic transformation of data. The nonlinear relationship between sensory and instrumental data could be attributed to two different phenomena. First, there could be distortion of the physical stimulus by the sensory system or loss of sensitivity as the intensity of the stimulus increases. Second, the type of sensory scale (i.e. 15 cm unstructured scales) used in this study may have caused the distortion. For example, Cardello *et al.* (1982) reported nonlinear relationships between sensory magnitude estimation scales and the sensory category scales

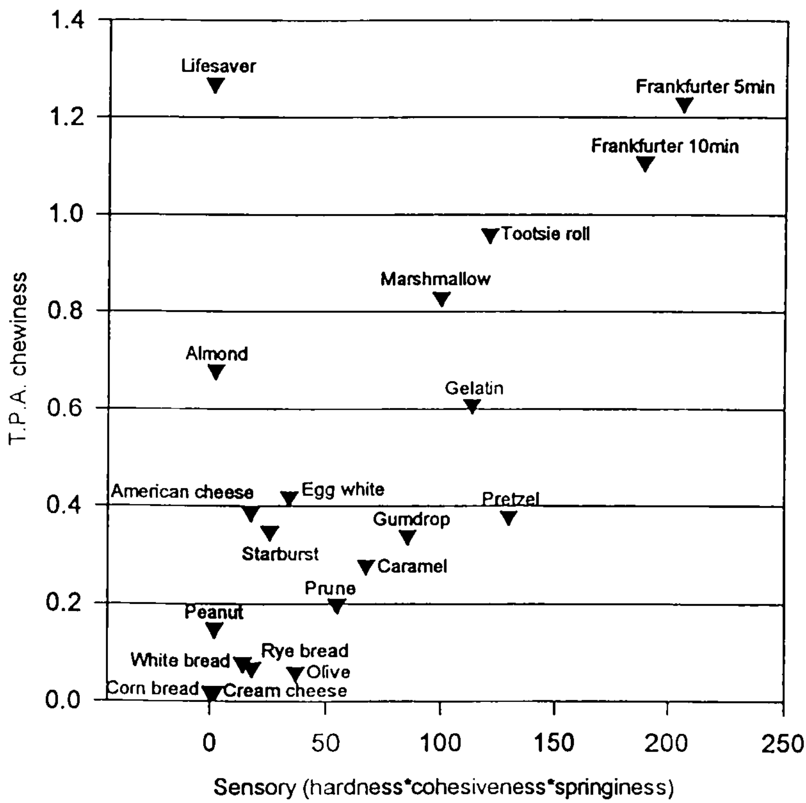

FIG. 2. T.P.A. CHEWINESS VS SENSORY (HARDNESS × COHESIVENESS × SPRINGINESS)

described by Szczesniak (1963). Nevertheless the scales used in this study were not the same as those described by Szczesniak, but were similar to corresponding continuous scales described by Munoz (1986). Furthermore, Moskowitz (1983) reported that a category scale with a large number of categories would approximate a ratio scale (magnitude estimation technique). In the case of the continuous 15 cm scale, the assumption can be made that it has an almost infinite number of categories, and therefore, closely approximated a ratio scale.

Correspondence Analysis. A multivariate approach to data analysis by a generalized procrustes analysis showed the spatial relationships of the four

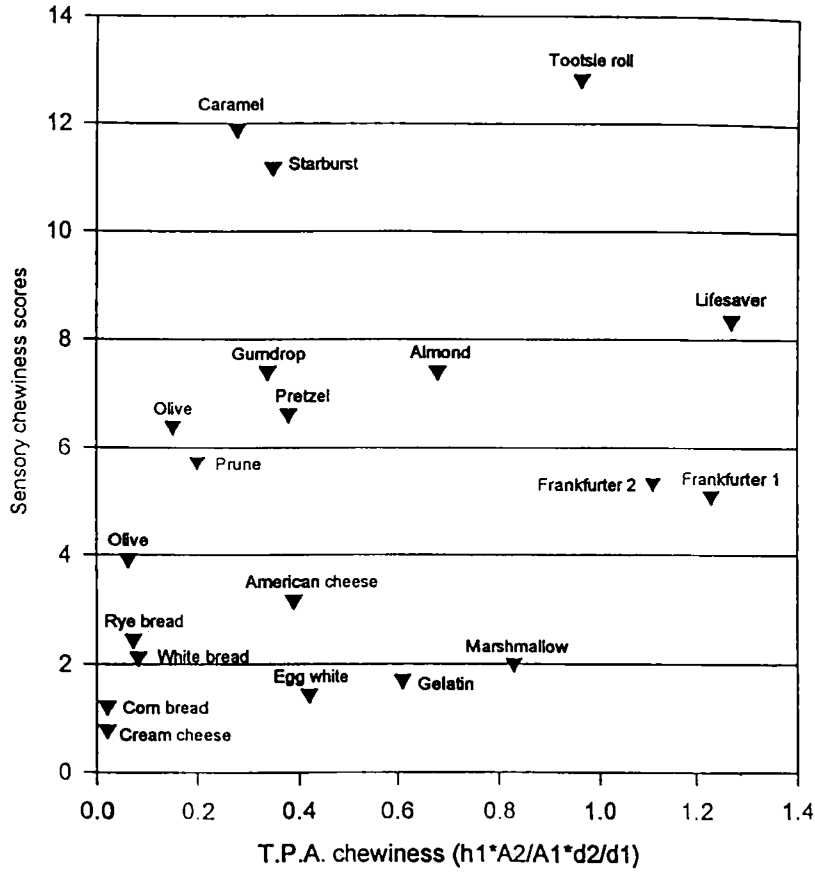

FIG. 3. SENSORY CHEWINESS VS INSTRUMENTAL CHEWINESS

sensory attributes and the corresponding factor scores for the individual food samples. A two-dimensional representation of this is presented in Fig. 4. If a rotatable model was visualized as circling around the point of origin of the axes, the contribution made by the dominant and nondominant sensory texture parameters can be seen. Products such as lifesaver, almond, peanut, and carrot were very close to the variable hardness. This showed that these products have a dominant sensory texture characteristic (i.e. hardness). Gelatin, marshmallow and egg white also presented a dominant characteristic (i.e. springiness), and did

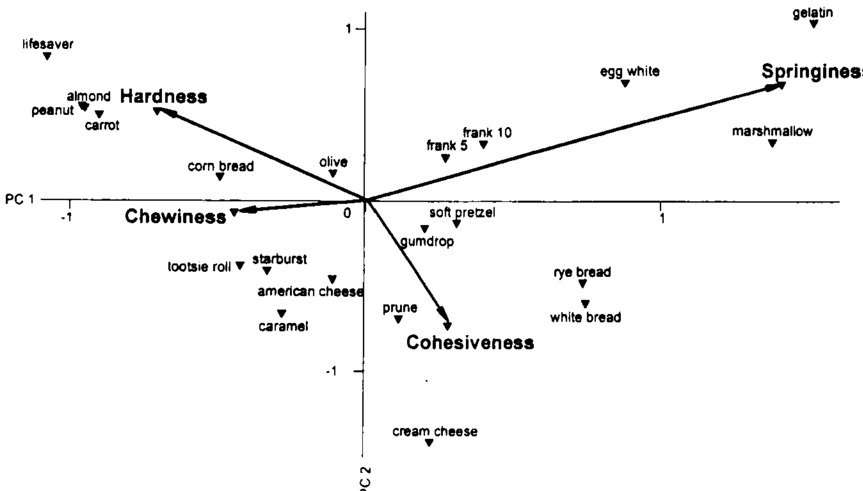

FIG. 4. CORRESPONDENCE ANALYSIS OF SENSORY ANALYSIS DATA

not show signs of an influence by nondominant characteristics (i.e. hardness, cohesiveness, chewiness). Caramel, starburst and tootsie roll were placed in the lower left quadrant between chewiness and cohesiveness. These products do not have a single dominant characteristic, but in fact, exhibited at least two primary characteristics (i.e. chewiness and cohesiveness). Products such as American cheese and cream cheese were placed in the lower half of the graph. Their placement was not because they were extremely cohesive or chewy, but because they lacked hardness and springiness.

CONCLUSIONS

The twenty-one food samples were shown to represent the spectrum of texture attributes found in foods (Fig. 4). High linear correlations were noted between corresponding objective parameters and sensory scores for hardness and springiness, but not for cohesiveness and chewiness. This was illustrated by problems encountered with the instrumental measurement of cohesiveness when dealing with foods that exerted little or no springiness. An instrumental measurement of cohesiveness producing reliable results independently of a product's springiness needs to be developed. The results also suggested that correlations between instrumental parameters and sensory attributes should be reported based on adequately chosen data transformations. Further work is needed to continue the search for understanding the sensory perceptions of texture and for instrumental tests that might relate to similar information as perceived by sensory evaluation. Meullenet *et al.* (1997) proposed to use multiple instrumental parameters to predict a single sensory attribute. This promising approach should be investigated further using a much larger database of samples.

REFERENCES

BOURNE, M.C. 1978. Texture Profile Analysis. Food Technol. *32*(7), 62-66, 72.

CARDELLO, A.V., MATAS, A. and SWEENEY, J. 1982a. The standard scales of texture: Rescaling by magnitude estimation. J. Food Sci. *47,* 1738-1742.

CARDELLO, A.V. *et al.* 1982b. Perception of texture by trained and consumer panelists. J. Food Sci. *47,* 1186-1197.

CIVILLE, G.V. and SZCZESNIAK, A.S. 1973. Guidelines to training a texture profile panel. J. Texture Studies *4,* 204-223.

FECHNER, G.T. 1860. *Elements of Psychophysics*. Translated by Helmut E. Adler (1996). Holt, Rinehart and Winston, New York.

FINDLAY, C.J., GULLETT, E.A. and GENNER, D. 1986. Integrated computerized sensory analysis. J. Sensory Studies *1*(3/4), 307-316.

LYON, C.E., LYON, B.G., DAVIS, C.E. and TOWNSEND, W.E. 1980. Texture profile analysis of patties made from mixed and flake-cut mechanical deboned poultry meat. Poultry Sci. *59,* 69-76.

MEILGAARD, M., CIVILLE, G.V. and CARR, B.T. 1992. *Sensory Evaluation Techniques*. CRC Press, Boca Raton, Florida.

MEULLENET, J.-F.C., CARPENTER, J.A., LYON, B.G. and LYON, C.E. 1997. Bicyclical instrument for assessing texture profile parameters and its relationship to sensory evaluation of texture. J. Texture Studies *28,* 101-118.

MONTEJANO, J.G., HAMANN, D.D. and LANIER, T.C. 1985. Comparison of two instrumental methods with sensory texture of protein gels. J. Texture Studies *16,* 403-424.

MOSKOWITZ, H.R. 1973. *Texture Measurements of Foods*. pp. 136-138, D. Reidel Publishing Company. Dordrecht-Holland/Boston, Mass.

MOSKOWITZ, H.R. 1983. *Product Testing and Sensory Evaluation of Foods: Marketing and R&D Approaches*. pp. 79-161, 236. Food & Nutrition Press, Trumbull, CT.

MOSKOWITZ, H.R. and KAPSALIS, J.G. 1976. *Psychophysical Relations in Texture.* Chapt. 19. pp. 554-581. In *Rheology and Texture in Food Quality.* (J. deMan *et al.*, eds.) Chapman & Hall, New York.

MUNOZ, A.M. 1986a. Development and application of texture reference scales. J. Sensory Studies *1,* 55-83.

MUNOZ, A.M., PANGBORN, R.M. and NOBLE, A.C. 1986b. Sensory and mechanical attributes of gel texture. II. Gelatin, sodium alginate and kappa-carrageenan gels. J. Texture Studies *17,* 17-36.

PANGBORN, R.M., SHARRAH, N., LEWIS, H. and BRANT, A.W. 1965. Sensory and mechanical measurements of turkey tenderness. Food Technol. *19,* 1268-1272.

SAS. 1985. *SAS User's Guide: Statistics,* 5th Ed., SAS Institute, Cary, N.C.

SCOTT BLAIR, G.W. 1969. *Elementary Rheology.* Chapt. 13 Psycho-rheology, measurement of sensations: Craftmanship. pp. 81-89, Academic Press, New York.

STEVENS, S.S. 1953. On the brightness of lights and the loudness of sounds. Science *118,* 576.

STEVENS, S.S. and MACK, J.D. 1959. Scales of apparent force. J. Experimental Psychol. *64,* 489-494.

SZCZESNIAK, A.S. 1968. Correlations between objective and sensory texture measurements. Food Technol. *22,* 981-985.

SZCZESNIAK, A.S. 1987. Review paper: Correlating sensory with instrumental texture measurements — An overview of recent developments. J. Texture Studies *18,* 1-15.

SZCZESNIAK, A.S., BRANDT, M.A. and FRIEDMAN, H.H. 1963. Development of standard rating scales for mechanical parameters and correlation between the objective and sensory methods of texture evaluation. J. Food Sci. *28,* 397-403.